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Processors of apple slices are constantly faced with difficulties in producing a product of uniform texture. The slices may range from a firm, excessively tough product to a soft, mushy one, may show different wholeness characteristics, and may exhibit various degrees of graining along the slice edge. These factors are influenced primarily by the variety, maturity, and storage history of the raw apple, as well as by in-plant processing techniques and handling (8). The texture of the processed product is assumed to be linked with that of the raw product; under standard processing conditions, the difference between the two is the degree of firmness or wholeness.

The textural problem is not one involving only the processor, but is also of great importance to the grower and packing-house operator.

An apple-quality study (8) has shown that textural aspects of processed apple slices accounted for about half of the quality grade. In this work exhaustive studies of the pectic substances, which were considered to be basically anhydrogalacturonic acids, did not account to a very great degree for the variations in firmness and wholeness of the slice. Kertesz (6) has reported little indication could be found that the initial firmness in apples (at harvest) is directly related to total pectin content or to the proportions of the various fractions. He does indicate, however, that changes in firmness which occur after harvest and during storage are probably related to pectic substances. Wiley and Thompson (8) have shown a close association between pectic substances and softening in storage for certain apple varieties, but not for others. To further confuse the issue of softening in the apple, the presence of pectases in firm-ripe apples has not been entirely confirmed (5). If pectic substances are principally responsible for softening, these pectases must be present in even the very immature apple.

Evidence is accumulating then, that carbohydrates other than pectic substances may play an important role in the initial firmness of an apple variety at harvest, in changes that take place during ripening in storage and in those changes that occur during thermal processing. Amounts and proportions of these materials, as well as their spatial arrangement in the cell wall, undoubtedly influence texture. This study presupposes that the textural change that takes place in the apple involves more than one of these substances.

Changes in texture during maturation and storage have historical-

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ly been considered to reside with the alcohol-insoluble solids (AIS), the structural materials. The main component parts of the AIS, which are starches, pectinic acids, hemicelluloses and cellulose, have been related in this study to the firmness of the raw fruit and the canned slices on both a fresh-weight and an AIS proportionality basis to determine the importance of each component. Statistical analyses were also used to ascertain the influence of each component in conjunction with the others. This procedure should indicate the substance or substances having the greatest influence on apple texture. Some theoretical considerations of a proposed starch-pectin-cellulose system involved in apple softening were also investigated.

Experimental Procedures

Fruit Harvest: Apples, 2½–3 inches in diameter, of 3 varieties, Golden Delicious, Stayman, and York Imperial were harvested at 4 stages of maturity starting September 15, 1959, and ending November 4, 1959. Two-bushel samples of each variety were processed and analyzed in the laboratory immediately after harvest. Also, each lot was removed from 34° F cold storage for processing and analysis at periods corresponding to 25, 50, 75, and 100 per cent of their average expected storage life (Table 1). Dates of harvest and removal from storage are reported in Tables 2, 3, and 4.

Table 1.—Description of cold storage conditions.

Variety	Storage interval between sampling	Total storage period
	days	*days*
Golden Delicious	26	104
Stayman	33	132
York Imperial	33	132

Pilot Plant Procedures: Apples which have been peeled, cored, trimmed, and sliced were processed by the regular vacuum-steam procedure and then canned as described by Wiley and Thompson (8). Shear-press readings, expressed in pounds force, were made on the raw slices (8).

Laboratory Analyses

AIS preparation and determination. At each sampling date, 500 gms. of ¼ inch thick apple slices were dropped in 900 ml of boiling 95% ethanol and held for 3 minutes. The alcohol was decanted and the slices were blended in the Waring blendor at 15,000 rpm for 5 minutes in an additional 600 ml of ethanol. The mixture was brought up to 1000 ml, poured into tin cans and sealed. Later, the contents of these cans were dried. Smaller aliquots of this dried material were purified by boiling in 80% alcohol. Per cent AIS of the fresh apple was determined on the basis of this sugar-free sample.

Table 2.—Effect of maturity and storage duration on measurements of Golden Delicious firmness (1959–60).

Storage	Alcohol insoluble solids (per cent)	Fresh weight basis: Starches (per cent)	Fresh weight basis: Pectinic acids total (per cent)	Fresh weight basis: Hemi-celluloses (per cent)	Fresh weight basis: Celluloses (per cent)	Per cent AIS basis: Starches (per cent)	Per cent AIS basis: Pectinic acids total (per cent)	Per cent AIS basis: Hemi-celluloses (per cent)	Per cent AIS basis: Celluloses (per cent)	Shear-press (pounds force)	Firmness (panel)
As harvested Sept. 15	2.99	0.31	0.58	1.65	0.45	10.50	19.36	55.10	15.04	566	+0.9
To Oct. 9	2.11	0.15	0.49	1.04	0.43	7.10	23.18	49.22	20.50	408	+0.7
To Nov. 5	1.98	0.02	0.45	1.00	0.51	1.20	22.55	50.40	25.85	234	−0.5
To Dec. 1	1.91	—	0.50	0.94	0.47	—	26.33	49.22	24.45	192	−0.7
To Dec. 29	2.02	—	0.39	1.10	0.53	—	19.32	54.45	26.23	211	−0.3
As harvested Sept. 23	2.37	0.23	0.50	1.19	0.46	8.90	21.27	50.33	19.50	544	+0.7
To Oct. 19	2.14	0.10	0.52	1.04	0.48	4.60	24.21	48.69	22.30	256	+0.1
To Nov. 12	1.98	0.03	0.50	0.91	0.55	0.90	25.32	45.87	27.91	190	−0.9
To Dec. 9	1.89	—	0.47	0.92	0.50	—	24.74	48.79	26.47	192	−0.9
To Jan. 5	1.93	—	0.47	0.90	0.56	—	24.22	46.56	29.22	206	−0.7
As harvested Oct. 5	2.19	0.16	0.47	1.15	0.44	7.31	21.55	52.36	18.78	426	+0.3
To Oct. 29	1.92	—	0.40	0.96	0.56	—	20.65	50.02	29.33	198	−1.3
To Nov. 25	1.79	—	0.39	0.90	0.51	—	21.67	50.06	28.27	170	−1.8
To Dec. 18	1.98	—	0.38	1.07	0.53	—	18.95	54.06	26.99	207	−1.3
To Jan. 15	2.01	—	0.47	0.93	0.60	—	23.96	46.38	29.66	155	−1.9
As harvested Oct. 14	1.86	—	0.41	0.96	0.50	—	21.84	51.45	26.71	315	+0.2
To Nov. 9	1.62	—	0.34	0.78	0.50	—	21.23	48.07	30.70	206	−0.5
To Dec. 4	1.66	—	0.40	0.77	0.49	—	23.97	46.27	29.76	168	−2.5
To Dec. 30	1.60	—	0.40	0.72	0.48	—	24.82	45.20	29.98	168	−2.5
To Jan. 25	1.49	—	0.33	0.70	0.47	—	22.13	46.67	31.20	150	−2.0
Means	1.97	0.05	0.44	0.98	0.45	2.03	22.57	49.46	25.94	258	−0.7

Table 3.—Effect of maturity and storage duration on measurements of Stayman firmness (1959–60).

Storage		Fresh weight basis				Per cent AIS basis					
	Alcohol insoluble solids (per cent)	Starches (per cent)	Pectinic acids total (per cent)	Hemi-celluloses (per cent)	Celluloses (Per cent)	Starches (per cent)	Pectinic acids total (per cent)	Hemi-celluloses (per cent)	Celluloses (per cent)	Shear-press (pounds force)	Firmness (panel)
As harvested Sept. 19	3.85	0.56	1.12	1.79	0.38	14.54	29.15	46.58	9.73	571	+1.6
To Oct. 23	2.65	0.28	0.75	1.24	0.38	10.51	28.35	46.84	13.40	565	+1.1
To Nov. 24	1.87	0.03	0.49	0.89	0.46	1.50	26.36	47.50	24.64	342	+0.7
To Dec. 28	2.04	0.02	0.48	1.00	0.54	0.80	23.36	49.16	26.68	258	+0.1
To Jan. 29	1.81	—	0.43	0.89	0.49	—	23.93	48.87	27.20	231	−0.8
As harvested Oct. 2	3.30	0.59	0.88	1.50	0.33	17.76	26.57	45.57	10.10	626	+1.7
To Nov. 3	2.15	0.15	0.51	1.09	0.39	7.13	23.68	50.88	18.31	364	+1.1
To Dec. 7	1.83	0.03	0.37	0.98	0.44	1.73	20.26	53.75	24.26	268	+0.2
To Jan. 7	1.92	—	0.37	1.03	0.52	—	19.36	53.47	27.17	282	−0.5
To Feb. 8	1.90	—	0.43	0.90	0.58	—	22.46	47.22	30.32	235	−0.7
As harvested Oct. 12	2.99	0.33	0.59	1.60	0.47	11.11	19.88	53.40	15.61	554	+1.3
To Nov. 13	2.09	0.09	0.52	0.97	0.51	4.49	24.84	46.34	24.33	360	+0.9
To Dec. 16	1.84	0.03	0.46	0.91	0.43	1.86	24.91	49.67	23.54	352	−0.1
To Jan. 18	1.74	—	0.32	0.95	0.47	—	18.11	54.72	27.17	240	−0.6
To Feb. 24	1.61	—	0.31	0.84	0.46	—	19.30	52.30	28.40	235	−0.5
As harvested Oct. 21	2.49	0.31	0.38	1.30	0.42	12.52	18.38	52.28	16.82	472	+1.5
To Nov. 20	2.03	0.15	0.50	0.96	0.42	7.58	24.81	47.07	20.54	438	+1.1
To Dec. 21	1.83	0.02	0.38	0.94	0.50	1.03	20.65	51.11	27.21	320	+0.1
To Jan. 27	1.73	—	0.34	0.85	0.55	—	19.48	48.96	31.56	233	−0.8
To Feb. 28	1.52	—	0.30	0.75	0.47	—	19.84	49.23	30.93	215	−1.3
Means	2.16	0.13	0.50	1.07	0.46	4.63	22.68	49.75	22.94	328	+0.3

Table 4.—Effect of maturity and storage duration on measurements of York Imperial firmness (1959–60).

Storage	Alcohol insoluble solids (per cent)	Fresh weight basis: Starches (per cent)	Fresh weight basis: Pectinic acids total (per cent)	Fresh weight basis: Hemi-celluloses (per cent)	Fresh weight basis: Celluloses (per cent)	Per cent AIS basis: Starches (per cent)	Per cent AIS basis: Pectinic acids total (per cent)	Per cent AIS basis: Hemi-celluloses (per cent)	Per cent AIS basis: Celluloses (per cent)	Shear-press (pounds force)	Firmness (panel)
As harvested Sept. 25	5.52	1.02	1.22	2.86	0.41	18.55	22.19	51.79	7.47	866	+1.4
To Oct. 27	3.53	0.39	0.78	1.99	0.37	10.97	22.18	56.47	10.38	603	+1.2
To Nov. 30	2.07	0.12	0.45	1.16	0.34	5.82	21.73	55.84	16.61	507	+0.9
To Jan. 4	2.42	0.04	0.52	1.32	0.55	1.70	21.29	54.39	22.62	442	+0.2
To Feb. 3	2.27	—	0.52	1.20	0.55	—	22.72	529.5	24.33	355	+0.1
As harvested Oct. 8	4.33	0.62	1.00	2.36	0.35	14.23	23.20	54.47	8.10	744	+1.8
To Nov. 10	3.01	0.25	0.45	1.73	0.59	8.26	14.97	57.35	19.42	708	+1.0
To Dec. 11	2.53	0.07	0.47	1.45	0.54	2.74	18.49	57.29	21.48	565	+1.3
To Jan. 14	2.62	0.05	0.58	1.44	0.55	2.06	21.97	54.91	21.06	500	+1.5
To Feb. 15	2.20	—	0.51	1.15	0.54	—	23.03	52.42	24.55	430	+0.7
As harvested Oct. 22	4.13	0.59	0.73	2.32	0.49	14.17	17.78	56.15	11.90	700	+2.0
To Nov. 23	2.74	0.19	0.63	1.45	0.48	6.78	22.94	52.83	17.45	650	+1.7
To Dec. 22	2.26	0.09	0.43	1.15	0.59	3.99	19.15	50.75	26.11	536	+0.8
To Jan. 28	2.40	0.06	0.46	1.24	0.65	2.35	19.11	51.60	26.94	486	+1.1
To Mar. 2	2.15	—	0.42	1.08	0.65	—	19.60	50.27	30.13	460	+1.1
As harvested Nov. 5	3.24	0.42	0.63	1.73	0.45	12.99	19.53	53.50	13.98	624	—
To Dec. 8	2.62	0.13	0.43	1.51	0.55	5.05	16.24	57.51	21.02	622	—
To Jan. 8	2.34	0.05	0.42	1.26	0.61	1.91	18.03	53.91	26.15	514	—
To Feb. 10	2.13	—	0.35	1.14	0.64	—	16.54	53.51	29.95	468	—
To Mar. 16	2.15	—	0.40	1.26	0.57	—	18.70	54.80	26.50	352	—
Means	2.83	0.20	0.57	1.54	0.52	5.58	19.98	54.14	20.31	557	+1.1

Pectinic acid and cellulose determinations. A 0.5 gram sample of AIS was held at 75° C in 30–35 ml of a solution containing 0.25% ammonium oxalate and 0.25% oxalic acid to extract all pectic substances. These samples were extracted 3 times with fresh solutions, using 1½-hour extraction periods. At the end of each extraction period the residues were filtered on a Buchner funnel through nylon cloth (72 × 112 fibers per inch). The residue was washed back into a beaker after each extraction, and after the last extraction the residue was retained for the next analysis.

The combined filtrate of the 3 extractions was brought to the phenophthalein end point (pH 8.1) with 20% NaOH and then acidified with 5 ml of 10% HCl. The filtrate was then precipitated with 200 ml of 95% ethanol and allowed to stand overnight. The total pectinic acid content was determined colorimetrically by the method of Ahmed and Scott (1), which uses versene, Pectinol 100 D, sulfuric acid and measures galacturonic acid in the ultra violet range (296 mu). Readings were calculated as per cent galacturonic acid. The majority of the pectic substances had been removed from the residue at this point in the analysis.

The residue from the pectin extractions was then held in 30–35 ml of 33% chloral hydrate (2, 2, 2,–trichloro–1, 1–ethanediol) for 16 hours at 75° C to remove starch. To insure complete removal of starch, the residue from this extraction was washed with chloral while filtering on the Buchner funnel. The filtrate was discarded. The remaining residue was then held in 30–35 ml of 10% KOH for 16 hours at 75° C to solublize the remaining hemicelluloses. A minute amount of Dow-Corning Antifomant A was added to prevent foaming. The AIS fraction which was insoluble in hot 10% KOH was considered cellulose. It was separated from the KOH solution by filtering on a weighed No. 1 filter paper, then washed copiously with distilled water and dried overnight at 100° C. This residue was then weighed and calculated as per cent cellulose on a per cent AIS and per cent fresh weight basis.

Starch Determinations. A separate 0.2 gm aliquot of the AIS was used for starch determination. Starches were determined colorimetrically by the method of Carter and Neubert (3), which considers the proportion of amylose to amylopectin to be 25–75. Starches were reported on a per cent AIS and per cent fresh weight basis.

Hemicelluloses were determined by difference.

Fats and coloring materials. These substances were determined by extracting the AIS for 7 hours with an isotropic mixture of benzene and absolute alcohol. Results were reported on a per cent fresh weight basis.

Additional Experiments.

1. Starches in pectin precipitates were determined colorimetrically using the method of Carter and Neubert (3).
2. Twenty-ml aliquots of pectinic acid precipitates which contained 10–40 mcg of starch were treated with 0.5 gms of clarase and

held at room temperature for 72 hours. Twenty-ml aliquots of pectinic acid precipitates which contained no starches were mixed with 50 mcg of soluble starch and treated as above. Residual starch was then determined by the iodine test (3).

3. Starches were found to influence colorimetric readings of galacturonic acid. Pectinol 100 D and/or sulphuric acid hydrolysis was shown to break down some of the starches into glucose. The influence of starch on colorimetric readings of galacturonic acid was checked by submitting standard starch solutions to the regular galacturonic acid procedure (1).

Organoleptic Procedures. Canned slices of each sampling were evaluated for firmness by a group of 20 judges from industry. They used a 9 point scale as follows: +4 inedible, +3 much too firm, +2 too firm, +1 slightly too firm, 0 ideal firmness, −1 slightly too soft, −2 too soft, −3 much too soft, and −4 mushy.

Statistical evaluation. Statistical analyses for the multiple regressions were done by a method of Kramer (7) fashioned after Snedecor (4). Data were analyzed on both a per cent fresh weight and per cent AIS basis.

Results and Discussioon

The results of the chemical analyses of the raw AIS, firmness of raw slices measured by the shear-press, and firmness values assigned by the panel to the canned slices are found in Tables 2, 3, and 4. Data for fats and pigments are not included since these substances amounted to only .042 per cent of the fresh weight of the apple flesh.

On a fresh-weight basis all varieties showed a decrease in starches, pectinic acids and hemicelluloses with increased maturity (harvests) and longer storage periods. Hemicelluloses were the largest part of the AIS. Celluloses tended to increase with greater maturity and longer storage periods (Figure 1). The average increase during storage was about 25 per cent, although a harvest of Golden Delicious, which was free of starch showed a decreasing trend. The most pronounced changes in these constituents were found during the first storage period.

Firmness differences among varieties appeared to be closely associated with gross amounts of AIS, i.e. starches, pectinic acids, hemicelluloses and cellulose. York Imperial firmness ranges of 866–352 lbs force were associated with AIS values of 5.52 to 2.13 per cent. Golden Delicious, a much softer variety, showed firmness values ranging from 566 to 150 lbs force, with AIS values of from 2.99 to 1.49 per cent. Stayman was intermediate in firmness. Apple varieties can best be classified according to firmness on the basis of the AIS value ranges found after commercial harvest.

On a per cent AIS basis, varieties also showed consistent trends in components of the AIS. Several important points were immediately noticed: 1) pectinic acids and hemicelluloses remained relatively constant in proportion to the other components of the AIS: 2) starches decreased rapidly; 3) cellulose increased as the

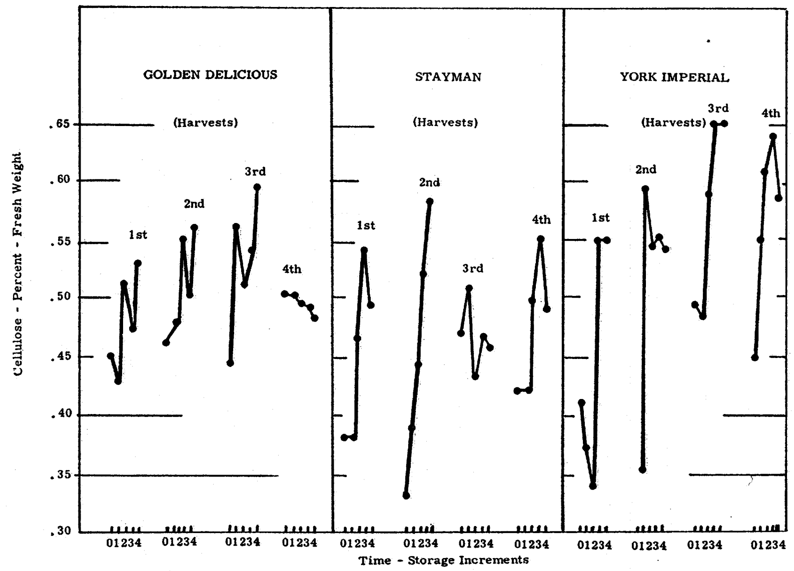

Fig. 1. Cellulose changes by harvest and storage times.

apples matured and/or ripened in storage; and 4) hemicelluloses made up about 50 per cent of the AIS.

On a proportionality basis, varietal differences in the AIS components centered mainly in the starches and cellulose. The firmer varieties had a higher proportion of starch and a lower proportion of cellulose. The pectinic acids and hemicelluloses did not vary significantly among varieties on an AIS proportionality basis.

Results of Correlations

The main emphasis of this study has been placed on determining the constituents or group of constituents which have the greatest influence on softening within an apple variety.

The first step has been to relate the AIS on a per cent fresh weight basis, to raw apple firmness (Table 5). The AIS values accounted for 63.8 to 79.7 per cent of the variation in firmness.

Since AIS values *per se* did not account for all firmness differences, the relationship of each fraction of the AIS to firmness was determined on both a fresh-weight and an AIS proportionality basis (Table 5). On a fresh weight basis, the starches showed the highest positive correlations with raw slice firmness and were considerably higher than similar correlations using total AIS values. The components of the AIS were then combined in a multiple regression, accounting for 80–90 per cent of the firmness variations within varieties. This was only a slight improvement over the correlation between starch and firmness.

As per cent AIS, starches were positively correlated and the cellulose was negatively correlated with firmness. The combined

Table 5.—Correlation coefficients between chemical constituents and raw slice shear-press values.

	Fresh weight basis			Per cent AIS basis		
	r	R^2	R	r	R^2	R
	Golden Delicious					
Total AIS	+.799			——		
Starch	+.946			+.942		
Pectinic acid	+.599			−.386		
Hemicellulose	+.813			+.539		
Cellulose	−.597			−.903		
All combined		.909	.953		.914	.956
	Stayman					
Total AIS	+.893			——		
Starch	+.931			+.957		
Pectinic acid	+.821			+.555		
Hemicellulose	+.867			−.349		
Cellulose	−.755			−.957		
All combined		.869	.932		.939	.969
	York Imperial					
Total AIS	+.872			——		
Starch	+.878			+.905		
Pectinic acid	+.745			−.033		
Hemicellulose	+.868			+.209		
Cellulose	−.516			−.872		
All combined		.808	.899		.844	.919

correlation of the individual components on an AIS proportionality basis accounted for more of the variation in firmness than did similar calculations on a per cent fresh-weight basis. A pronounced negative correlation between firmness and cellulose undoubtedly improved the correlation on an AIS proportionality basis. These data indicate that softening of an apple variety during maturation and ripening is more closely associated with the proportionality of the starches, pectinic acids, hemicelluloses and cellulose of the AIS than with fresh-weight values.

The partial regression coefficients expressed in per cent are presented in Table 6. These data show that starches are closely correlated with apple firmness.

Table 6.—Relative importance of AIS constituents in terms of firmness.

	Partial regression coefficients expressed in per cent	
	Fresh weight basis	Per cent AIS basis
	Golden Delicious	
Starch	68.2	48.5
Pectinic acid	8.8	6.4
Hemicellulose	16.1	16.5
Cellulose	6.9	28.6
	Stayman	
Starch	66.4	60.4
Pectinic acid	4.2	20.1
Hemicellulose	16.7	12.8
Cellulose	12.8	6.8
	York Imperial	
Starch	48.3	43.1
Pectinic acid	27.0	21.3
Hemicellulose	24.2	9.3
Cellulose	0.5	26.3

Theoretical Considerations

Changes in starch, and perhaps cellulose, appear to be responsible for the majority of the softening in the apple, both on the tree and in storage. There is a negative correlation between starch and cellulose. The initial softening is associated with starch decrease and cellulose increase. Further softening is due to changes in pectinic acids and hemicelluloses. These assumptions apply to apples picked during commercial harvest and processed before excessive storage.

It is possible that the accumulation of starch grains found in early harvest apples lend firmness to the tissue. These grains are soon dissipated from the apple tissue.

Additional Experiments

Starch-like substances were closely associated with pectinic acids. It was impossible to separate these starchy polyglucoses from the pectinic acid precipitates with clarase, a starch-hydrolytic enzyme. A colorimetric determination of starch-like substances in the pectin precipitates gave values about one-fourth as great as those for total starch. There was a higher amount of starch in the pectinic acid precipitates of the early-harvest apples than in those of late-harvest. The average percentage of the total starch which was associated with the pectin precipitates is similar to that reported as the percentage of amylose in apple starch. The iodine reaction with these starchy polyglucoses was deep blue, indicating that these substances may be of the straight-chain amylose type.

The enzyme-treated samples of starchy precipitates of pectinic acids showed little decrease in the blue color when given an iodine test after 72 hours. Other pectinic acid precipitates known to contain no starch, when mixed with soluble starches of the same concentration, gave no color reaction with iodine after 6 hours of enzyme treatment. This indicates a chemical union between the apple pectinic acids and these starch-like substances and parallels the findings of Carson and Maclay (2). Working with hemicelluloses, these investigators found anhydroglucose units chemically united with the anhydroxylose of lima bean pods and corn cobs. The apparent invulnerability of this starch-like substance to starch hydrolyzing enzymes indicates that it bears some similarity to pectic substances.

Because of the apparent union between these starchy polyglucoses and pectinic acids, it was suspected that these substances and perhaps a fraction of soluble starches could be hydrolyzed into glucose by Pectinol 100D. A fraction of the soluble starches appeared to be susceptible to hydrolysis by Pectinol 100D. However, this action could be due to an unidentified enzyme, to a combination of the pectases in the Pectinol 100D or sulphuric acid hydrolysis. This is additional evidence that these starchy polyglucoses are quite similar to pectic substances. This finding also indicates that starch-hydrolytic enzymes should be used to dissipate all free starch before the colorimetric determinations of galacturonic acid.

Starch–Pectin–Cellulose System

These experiments have shown the possibility of an intermediate substance between starches and pectic materials, a straight chained polyglucose, susceptible to pectase as well as amylase action. The disappearance of this substance occurs during the principal softening period of the apple. As the starches were depleted in the apple, there was an apparent increase in cellulose (Figure 1). The mechanism of cell wall thickening in apples may be related to starches. It is possible that starch degradation products react with galacturonic acid, and are then condensed into cellulose. If this is the case, starches supply glucose units, pectinic acids act as intermediates, and cellulose is the end product. This process could account for the initial and major part of the softening of the apple. Hemicelluloses, which are rather constant in proportion to the other substances, may also act as intermediates in this process, particularly if the results of Carson and Maclay (2) are applicable to apple hemicellulose.

Practical Applications

The processor may determine the starch content which will give the most desirable slice from the standpoint of firmness (Table 2–4, Figure 2). It appears that raw slices containing 0.05–0.1 per cent starch on a fresh-weight basis or 5 per cent on an AIS proportionality basis gives the most desirable quality slice.

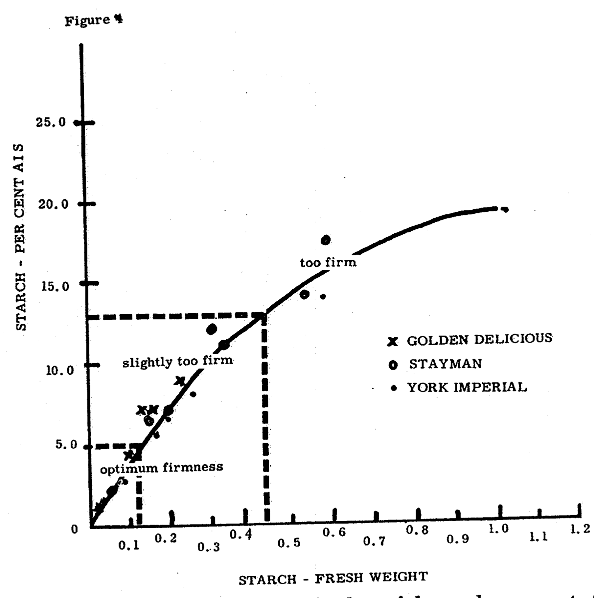

Fig. 2. Relationship between starches fresh weight and per cent AIS basis.

Summary and Conclusions

Firmness ranges among apple varieties were closely associated with the amounts of AIS present at harvest and during storage. All constituents of the AIS were higher in a "firm" type apple as compared with a "soft" type on a fresh-weight basis. On an AIS proportionality basis the "firm" type contained a greater proportion of starch and a smaller proportion of cellulose than the "soft" type.

Within varieties softening of apples of varying maturity and ripeness was due to a decrease in the total AIS, as well as to a change in the proportions of the various components of the AIS. Of these components, starches on a fresh-weight basis, and starches and cellulose on an AIS proportionality basis appeared to be the most important factors governing softening.

Starch-like substances (polyglucoses) and pectinic acids were intimately associated in the pectinic acid precipitates. It is assumed that the same union occurs in the living tissues. These complexes could not be separated completely with the use of starch hydrolyzing enzymes, indicating a chemical rather than a physical union between these substances. The average starchy polyglucose content of these pectinic acid precipitates was about one-fourth of the starch content present in the total AIS. This percentage corresponds rather closely with the amylose content of apple starch. The presence of these substances was particularly pronounced during the primary softening phase of the raw apple.

Since starches and/or starch-like substances may cause interference in the colorimetric determination of galacturonic acid, they should be removed as completely as possible prior to analysis.

Correlation coefficients between starches and cellulose, particularly on an AIS proportionality basis, were —0.9 or higher among varieties. As starches decreased in proportion, celluloses increased, indicating a link between these substances.

The starchy polyglucose-pectinic acid association and the AIS proportionality relationship between starches and cellulose would indicate a possible pathway by which highly insoluble wall thickenings may be produced. During the transition of these substances, the greatest amount and rate of softening in the raw apple takes place; secondary softening at lower rates is due to changes in the pectinic acids and hemicelluloses.

The determination of the firmness of processed apple slices by measurement of starches in the raw slices may be feasible. This can be done colorimetrically and would include the starches in starch granules, as well as the starchy polyglucoses in the cell walls. Raw slices with 0.05–0.1% starch on a fresh-weight basis or 5% on an AIS proportionality basis will yield a product of optimum firmness. Apple slices with greater amounts of starch were tough and rubbery, while those which had no measurable amount of starch were soft. These relationships were very consistent among varieties, as optimum textured slices (including firmness and wholeness) for all varieties were those processed just as the starches were dissipated from the tissues.

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